MATLAB EXPO 2019

Deploying AI for Near Real-Time Manufacturing Decisions (Masterclass)

Pallavi Kar Application Engineer – Data Science & Enterprise Integration



Digital Transformation and IIoT

Customer Goal

By connecting machines in operation,

you can use data, algorithms, and models

to make <u>better decisions</u>, improve processes, reduce cost, improve customer experience.

Industrial IoT

- Digital Twin
- Industry 4.0
- Smart 'XYZ'
- Digital Transformation







Predictive Maintenance

TV

- Operating Conditions vary over time and location
- Component Life and Safety



Blowout Preventer Control System: **Condition and Performance Monitoring** Mete Mutlu, John Kozicz

Transocean performed CPM of a BOP using an adaptive physics-based modeling approach with Simscape Link



Case Study: Transocean

Objective: Reduce BOP downtime

Solution:

- Simulink model of BOP and Control System
- Simulate 100s future scenarios degradation trends and anomalies
- Pi Servers to collect data
- Preprocess data to avoid noise and outliers
- Train Models on future scenarios to predict in advance

Outcome: Robust condition and performance monitoring of BOP reduced downtime







Example Problem: Develop and operationalize a digital twin and a machine learning model to predict failures in industrial pumps

Current system requires Operator to manually monitor operational metrics for anomalies. Their expertise is required to detect and take preventative action





Process Engineer

Develops models in MATLAB and Simulink



System Architect

Deploys and operationalizes model on Azure cloud



Operator

Makes operational decisions based on model output



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Predictive Maintenance Workflow



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Backbone Infrastructure for Preventive, Predictive, Reactive, Actionable Analytics







Steaming Analytics - Remaining Useful Life



Edge Device Publishing Data

Consume data and Update RUL

Project statement: Develop end-to-end predictive maintenance system





- 2. Need an *alert* when fault parameters drift outside an acceptable range so I can take *immediate corrective action*
- Continuous estimate of each pump's *remaining useful life (RUL)* so that I can schedule maintenance or replace the asset



Project constraints and solutions



We don't have a large set of failure data, and it's too costly to generate real failures in our plant for this project

Process Engineer

Solution: Use an accurate physics-based software model for the pump to develop synthetic training sets

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Project constraints and solutions



Need software for multidisciplinary problem across teams, plus integration w/ IT

Process Engineer

Solution: Use MATLAB and integrate with OSS



Project constraints and solutions



We don't have a large IT/hardware budget, and we need to see results before committing to a particular platform or technology

System Architect

Solution: Leverage cloud platform to quickly configure and provision the services needed to build the solution, while minimizing lock-in to a particular provider

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Process Engineer

- Crankshaft drives three plungers
 - Each 120 degrees out of phase
 - One chamber always discharging
 - Three types of failures







Creating Multi-Domain Physical Models using Simscape







Pump Hardware



Acquire Real-Time Data for Updating Digital Twin





Use Simulink Design Optimizer to



Parameter Estimation* - HydroElectricTwinModel	EstimatedParams	-
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- ✓ Setup Experiments
- ✓ Parameterize
- ✓ Save Sessions
- ✓ Generate Code

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Access and Explore Data

Build digital twin and generate sensor data





Simulate data with many failure conditions



Run parallel simulations

Access and Explore Data

Store data on HDFS

A MathWorks

Predictive Maintenance Workflow





Preprocess Data

Represent signal information

Process Engineer


Time (ms)



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Diagnostic Feature Designer App

Predictive Maintenance Toolbox R2019a

- Extract, visualize, and rank features from sensor data
- Use both statistical and dynamic modeling methods
- Work with out-of-memory data
- Explore and discover techniques without writing MATLAB code







Develop Predictive Models in MATLAB

Process Engineer







Develop Predictive Models in MATLAB

Process Engineer

		1	2	3	4
	Time	LeakFault	BlockingFault	BearingFault	FaultType
1	0 sec	2.8472	-0.1477	1.8000	All
2	0.001 sec	-0.1498	-0.4207	1.3103	Bearing & Blocking
3	0.002 sec	0.6511	1.6521	-0.5557	Leak
4	0.003 sec	0.1469	-0.2775	1.0074	All
5	0.004 sec	-0.6480	0.7065	-0.8878	Blocking
6	0.005 sec	-0.8165	-0.5434	-0.3079	Blocking
7	0.006 sec	-1.0061	1.2083	0.0661	Bearing
8	0.007 sec	1.0125	-1.9098	-0.7027	Leak & Blocking

Label Faults

Scale

tt = tall(ds); tt = preprocessData(tt); model = TreeBagger(50,tt,'Event');

Evaluating tall expression using the Spark Cluster: - Pass 1 of 2: Completed in 11 sec - Pass 2 of 2: Completed in 2.3333 min Evaluation completed in 2.6167 min



Validate Model





Develop Machine Learning Models

Process Engineer







Estimate Remaining Useful Life







Develop a Stream Processing Function

Process Engineer

- Batch Processing: Build and test model on simulated data



• Stream Processing: Apply model to sensor data in near real-time







```
new_state = updateState(data,old_state);
```

Write results

```
writeResults(Leak,Blocking,Bearing,FaultType,RUL,Model)
end
```



Prototype Predictive Maintenance Architecture on Azure





What does a streaming function look like?





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Clear All Requests

Save Log Clear Log



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Test and Debug Streaming Function

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Package Stream Processing Function

Process Engineer

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Package and Test to generate compiled archive

Process Engineer 4

Integrate with

Production Systems

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Compiled Package and Runtime requirements

Process Engineer

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Integrate with

Production Systems

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Starting MATLAB Production Server Dashboard

Process Engineer

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Deploying Streaming Function on Production System

Process Engineer

4

Integrate with

Production Systems





MathWorks



4

Integrate Analytics with Production Systems

System Architect





MATLAB Production Server on Azure

Integrate with

Production Systems

4





MathWorks Cloud Reference Architecture

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Serving REST Calls on Production Server

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MathWorks Reference Architectures

mathworks.github.io

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matlab-aws-s3	matlab-azure-blob	matlab-parquet
MATLAB interface for AWS S3.	MATLAB interface for Windows Azure Blob Storage.	MATLAB Interface for Apache Parquet
MATLAB Updated 26 days ago	MATLAB Updated on Feb 21	MATLAB 🛧 1 Updated on Dec 20, 2018
matlab-azure-data-lake	matlab-aws-common	matlab-avro
MATLAB Interface for Azure Data Lake.	Code common to MATLAB interfaces. Code in this repository is used as a	MATLAB interface for Apache Avro files.
MATLAB Updated on Feb 21	dependency for other projects such as matlab-aws-s3.	MATLAB Updated on Feb 9
	MATLAB Updated on Feb 21	





Review System Requirements

- Requirements from the Process Engineer
 - Every millisecond, each pump generates a time-stamped record of flow, pressure, and current
 - Model expects 1 sec. window of data per pump
 - Initially, 1's 10's of devices, but quickly scale to 100's
- Requirements from the Operator

Integrate with Production

Systems

System Architect

- Alerts when parameters drift outside the expected ranges
- Continuous estimating of RUL for each pump









Operator



Integrate Analytics with Production Systems

System Architect







Connecting MATLAB Production Server to Kafka

- System Architect
 - Connector feeds single Kafka topic to a MATLAB function
 - Publisher library for MATLAB for writing to a results stream
 - Connector Features:
 - Deploy as a micro-service with Docker
 - Drive everything through config
 - Group data into time windows and pass to MATLAB as a timetable
 - Use Kafka's check-pointing (i.e. at-least-once)





Setting up the Kafka Connector

#!/usr/bin/env bash	
BASE=\$(pwd)	
echo "BASE: \${BASE}"	
MPS_HOME=\$BASE KAFKA_CONNECTOR_DIR=\${MPS_HOME}///kafka-connector/Software/Java MPS_CLIENT=\${KAFKA_CONNECTOR_DIR}/client/java/mps_client.jar KAFKA_CONNECTOR=\${KAFKA_CONNECTOR_DIR}/lib/com/mathworks/mps/kafka-connector/1.1.0/kafka-connector-1.1.0-jar-wi\$ CLASSPATH=\${MPS_CLIENT}:\${KAFKA_CONNECTOR}	Libraries
# CLASSPATH=\${CLASSPATH}:\${MPS_HOME}/lib/com/mathworks/mps/kafka-connector/1.1.0/kafka-connector-jar-with-depen\$	
export GROUP_ID=mpsstuff export CONNECTOR_TOPIC=to-mps export CONNECTOR_TOPIC_OUT=from-mps export MPS_CONNECT=http://localbost:9910	
export MPS_ARCHIVE=PumpFault export MPS_FUNCTION=streamingFunction	Configuration
export BOOTSTRAP_SERVERS=tocathost.9092 export MPS_DISPATCH_FUNCTION=pumpconsume # Skip or stop export MATLAB_ERROR_ACTION=skip	
echo "CLASSPATH == \${CLASSPATH}"	
exec java -cp \${CLASSPATH} \ -Dlog4j.configuration=file:\${MPS_HOME}/config/log4j.properties \ com.mathworks.mps.client.kafka.KafkaConnector_\$@	





System Architect





Streaming data is treated as an unbounded Timetable

System Architect

Input Stream

Event Time	Pump Id	Flow	Pressure	Current
40.04.40	D	4075	400	440
18:01:10	Pump1	1975	100	110
18:10:30	Pump3	2000	109	115
18:05:20	Pump1	1980	105	105
18:10:45	Pump2	2100	110	100
18:30:10	Pump4	2000	100	110
18:35:20	Pump4	1960	103	105
18:20:40	Pump3	1970	112	104
18:39:30	Pump4	2100	105	110
18:30:00	Pump3	1980	110	113
18:30:50	Pump3	2000	100	110
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	State			Pump3			
				Pump4			
		18:10:00	18:20:00	Pump2	7		
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				Pump4			
		18:20:00	18:30:00	Pump1			
	State			Pump3	4		
				Pump4			
•	MATLAB	18:30:00	18:40:00	Pump5			
	Function			Pump3	5		
				Pump4	8		
	State						





Messaging adapter for Production Server

- Bridges streaming data and Production Server Async Java Client
- Batches incoming messages and sends them via HTTP request/response
 - Time windows, event time processing, and out-of-order data
- Uses Asynchronous pipeline model with back-pressure
 - Kafka consumers are automatically paused when server is busy
- Supports sequential (stateful) and unordered (stateless) processing
 - Provide unique stream ID/topic/partition info for persistence layer
- Pass data as MATLAB timetables
- Partition aware enables full exploitation of partition-based parallelism



Creating persistence

Process Engineer





Attaching persistence

Process Engineer

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Integrate with

Production

4



58





Debug your streaming function on live data

System Architect





4

Debug a Stream Processing Function in MATLAB

System
Architect

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	22 % Model doesn't work well with too few data points.	=
	23- limit = 100;	
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	26 height (data). limit):	
	27 - new state = old state;	
	28 - return;	
	29- end	
	30	
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	32 to Get the keys present in the data, use categorical for performance	
	<pre>34 pumps = string(categories(data.key));</pre>	
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	36 % Load models	
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	39- if isempty (leakModel)	
	40 x = Total ("mnodels.mat"); 41 leakMedel = x leakMedel :	
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Running Kafka with MPS

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Complete your application

System Architect





Visualize Results

5

Complete Your Application

Plant Operator

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Build Standalone UI based applications in MATLAB





MATLAB, Simulink and Cloud Reference Architectures provide "Integrated AI Development and Deployment Workflow" for Cross Functional Teams

- Successfully use Digital Twins to generate faults and train models
- Fast prototyping of physical and AI models with MATLAB
- Easy integration with OSS
- Cloud reference architectures for enabling faster IT setup
- Customize dashboard for Operator's needs



"By creating standalone operational

programs using MATLAB Compiler and

Resources to learn and get started

- <u>GitHub: MathWorks Reference</u>
 <u>Architectures</u>
- Working with Enterprise IT Systems
- Data Analytics with MATLAB
- Simulink



MathWorks Products Solutions Academia Support Community Events

MATLAB Works with Your IT Systems

MATLAB® code is production ready and can be securely deployed and integrated with enterprise

IT systems, data sources, and operational technologies. IT can partner with engineering teams to:

Enterprise and IT Systems

MATLAB EXPO 2019

Thank You

